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High Temperature Superconductivity Research in Selected Laboratories in West Germany

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The superconductivity work at eight West German laboratories is reviewed. The laboratories are (or located at): the University of Giessen; the Technical University at Darmstadt; Hoechst AG; Siemens AG; KFA Jülich; KFK, Karlsruhe; the Walter Meissner Institute, Garching, and the Max Planck Institute, Stuttgart.

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Contents

High Temperature Superconductivity Research in Selected Laboratories in West Germany

Introduction

At the invitation of H. Dr. Hans Donth, Deputy Assistant Secretary, Federal Ministry for Research and Technology (BMFT), we, the authors, were invited to visit laboratories in the Federal Republic of Germany (FRG) to discuss research in progress on the high temperature superconducting materials. Dr. Magdala Gronau, Verein Deutscher Ingenieures (VDI), acted to arrange the visits and accompanied us on several of them. The visits occurred between 21 and 27 February 1988, fol-lowing by about a month the announcement of the BiCaSrCu-O – another of the high temperature superconductors. The laboratories visited included those of universities at Giessen and Darmstadt, those involved in industrial research at Hoechst and Siemens, and the federally supported laboratories at the Walther Meissner Institute at Garching, the Max-Planck Institute at Stuttgart, the Kernforschungsanlage (KFA) at Jülich, and the Kernforschungszentrum Karlsruhe (KfK) at Karlsruhe.

Details of the research we discussed are given below under the institutional headings. First there are some general comments regarding the German response to the opportunities in this area of high temperature superconductivity. Then brief descriptions of the eight labs visited are given followed by some general conclusions about the current position of the research we observed relative to what we know is in progress in the US.

Some research groups in Germany, such as KfK, Darmstadt, and Giessen, have a long history of research and development of superconductivity and, not surprisingly, these groups have developed quickly in high temperature superconductivity research. Government support of superconductivity research from the BMFT had been tapering off, from DM4 million/year to 1-2 million/yr (~ $2.5 to $0.6-$1.2 million [at current rate of exchange $1.00 = DM1.58]). In FY87 the level was stepped back up to DM4 million with some additional new funds and reprogrammed funds. This included DM 0.8 million made available very early in 1987 for equipment purchases by existing groups. The expected level in FY88 is DM16 million that will be mostly new funds provided by separate legislative action. Planned support for FY89 is anticipated to be DM35 million with a further increase hoped for in FY90 to DM45 million.

The BMFT program consisted of four major thrusts: (1) development of superconducting magnets, (2) cryogenics, (3) development of practical superconductors including new materials, and (4) new applications of superconductors. While BMFT support of university-industrial collaboration is normally 50 percent of the industry cost and 50 percent of the university cost with industry paying for the other 50 percent of the university costs, support for high T_c materials will be provided at 50 percent to industry and 75 percent to university, thus reducing the industry support and product-oriented influence on the initial university studies. Such a plan would remain in effect for 4 to 5 years.

In addition to the research and development funds in superconductivity there is specific support in medical applications and for an electric generator construction at DM25 million/year each. Accelerator physics applications are funded by other mechanisms also.

Donald H. Liebenberg is a scientist in the Low Temperature Physics Program, National Science Foundation. Dr. Clark is the Liaison Scientist for Superconducting Materials and Electromagnetics in Europe and the Middle East for the Office of Naval Research's London Branch Office. He is on leave until March 1989 from the National Bureau of Standards in Boulder, Colorado, where he is Group Leader of the Superconductor and Magnetic Measurements Group.

Brief Descriptions

University of Giessen. The group at Giessen has been developing superconducting electronics with classical superconductors for some years and is producing some of the best and quickest results as part of the development of new superconductor circuit elements.

Technical University at Darmstadt. Based on a long history in low temperature superconductivity research, the Darmstadt group has developed a number of experimental techniques for determining the fundamental properties of the new superconductors.

Hoechst AG. The Hoechst company's recently acquired businesses in ceramics have produced a substantial and long-range commitment to the development of the new superconductors, including the recent BiCaSrCuO compound.

Siemens AG. Extensive experience in conventional superconductors which are being marketed and further developed has placed Siemens in a very strong position with expertise and commitment to develop the new superconductors including the BiCaSrCuO materials.

Kernforschungsanlage, Jülich. The current research in high temperature superconductors extends over the 10 KFA institutes with reorientation and strengthening

planned in the area of thin films of both superconductor and semiconductor materials.

Kernforschungszentrum Karlsruhe. The long-term commitment to superconductivity research at KfK has produced recent significant advances in the conventional superconducting materials, NbN and $PbMoS_8$. The wide range of expertise and planned long-term future effort seems certain to yield substantial gains in fundamental understanding and in technological developments in the new materials that will keep KfK at the forefront.

Walther Meissner Institute, Garching. This institute's contributions to fundamental physical properties have been carefully accomplished with limited resources combined with capable expertise.

Max Planck Institute, Stuttgart. At MPI-Stuttgart excellent optical measurements and advanced materials preparation has produced seminal work in understanding the lattice vibrational properties and chemistry of the new high temperature superconducting materials, including prompt work with BiCaSrCuO.

Conclusion. The eight university, federal, and industrial laboratories that were visited represent a small, but high-quality, set of laboratories in Germany doing research in high temperature superconducting materials. We observed that long-term, steady support of superconductivity in each setting has provided both significant expertise in individuals and marketable products. The fast pace of developments stresses the existing mechanisms of communication, and we saw evidence where improved communications would be helpful; this situation is not dissimilar from that in the US. The future prospects are being nurtured with increased federal funding and corporate commitment on a time scale that appears to be consistent with the expectations for improved fundamental understanding closely followed by the development of applications. This also has a positive effect on the careers of young scientists where this commitment will provide opportunities to establish their professional stature in this field.

Finally, we express deep appreciation to our hosts, Dr. H. Donth, Dr. Gronau, and the BMFT, to the several laboratories and their management and staff, and to our home organizations, the NSF and ONR, for providing this useful glimpse into high temperature superconducting research in West Germany

Detailed Reviews of the Laboratories

Technical University of Darmstadt

In the chairman's (Professor Steglich) absence, Professor Weber described the current work of the Institute of Solid State Physics. He noted the various funding modes within the Deutsches Forschung Gemeinschaft (DFG). The normal procedure in which a professor applies for support has been augmented by a procedure to support a focused project that loosely connects several professors. This is called a Sonder Forschung Bereich (SFB) (or Special Research Field), and Steglich's group is part of such an effort – titled "Highly Correlated Materials" – that involves about 55 people at a number of universities. The support at Darmstadt is DM 400,000/year ($250,000) spread over several departments. Overall the SFB commits DM400 million/year or between one-half and one-third of the DFG total budget. Professor Steglich has additional support as 1988 winner of a Liebnitz Prize for young professors of DM3 millions over 5 years. The group has some seven Ph.D. and about 10 Diploma students. Strong support for new materials studies comes from the Hochshule president. The Steglich group is well known for very low temperature studies of new superconductors and, more recently, for major contributions in the research on heavy fermion systems.

Measurement techniques the group has developed include specific heat, magnetization, ac and dc susceptibility, Meissner effect, and thermal expansivity for use in the temperature range of at least 0.1-100 K. The specific heat jump and the thermal expansion peak at T_c were shown for a sample of YBaCuO prepared by Siemens. For thermal conductivity a T^3 phonon contribution term and a linear term were found at low temperature. The linear term was seen for all O_7 samples but not seen for the O_6 sample. The linear term in specific heat is not believed reliable by Weber [but has been observed by others; i.e., University of Illinois].

Measurements of the thermal expansivity of the $LaSrCuO_4$ material were approximately linear below and above the transition, decreasing in a broad region near T_c. The Ehrenfest relations were used to obtain a value dT_c/dP that agrees with direct measurements. A new Oxford dilution refrigerator was being installed although leak problems in the heat exchanger were slowing progress.

This group has developed a number of techniques such as the capacitance dilatometer and high-frequency susceptibility for measurements of small samples in this low temperature region.

University of Giessen

The Institute of Applied Physics of the University of Giessen has long had a focus on the development of superconducting devices of higher critical temperature, using the conventional superconductors. About one-half of the total of 40 people (20 scientists plus support staff and students) work on superconducting electronics, primarily analog circuits, under the direction of Professor Heiden. Good success with the higher T_c conventional superconductors such as Nb_3Al, Nb_3Ge, and NbN provides a sound basis for studying the new oxide superconductors. Some of the highlights of this past work are a Nb_3Ge switch with a 2-nanosec switching time, a Mo_3Si zero gauss cylinder with 10^{-4} gauss, a NbN dc superconducting quantum interference device (SQUID) as a

relaxation oscillator, and a gradiometer with a slew rate of 20×10^6 flux quanta/sec – all of which can operate up to liquid hydrogen temperatures. Heiden's group has also made and used NbN SQUIDS for fundamental magnetization studies of single 30-μm-diameter Fe particles, for example.

In the new high T_c oxide superconductors, they have made dc SQUIDS with two microbridges of about 30 μm on MgO substrates with $T_c(0)$ of 75 to 82 K and lockable operation at 70 K. The weak links contain many junctions, and Professor Heiden stated the problem as being "not to make junctions but to *not* make junctions!" With 11 different preparation systems, both reactive plasma etching and lift-off technique, and less than 0.1-μm lithography capability, the group is well positioned to pursue superconducting circuit elements with the new materials and is actively pursuing the many parameterization studies needed.

In the adjacent Inorganic and Analytical Chemistry Institute, Professor Gruehn has studied perovskite structures such as $Nb_{11}W_{15}O_{69}$ for many years. In some excellent tranmission electron microscopy (TEM) studies of the twin boundaries in YBaCuO, he has shown the twin boundary to be only 1 or 2 cells wide and also a slight misalignment of the a-b to b-a axes. The variation of the TEM contrast with both sample thickness and defocusing voltage shows many different patterns and provides a reason for real caution on making too literal interpretations of TEM patterns.

The group at Giessen has shown some of the best and quickest results in developing circuit elements with the new materials.

Hoechst AG, Frankfurt

The Hoechst company is a large, diversified company with 180,000 persons employed worldwide, 38,000 in Frankfurt. The company provides substrates, carriers, chemicals, piezoceramics, and many other items to the electronics industry. The Corporate Research II Group includes engineering, applied physics, and ceramics research groups. Because of its background in pharmaceuticals, the company has apparently approached the support of high T_c by assuming significant development costs and, accordingly, has hired additional people to work on this project. Dr. Marcell Peuckert discussed the high T_c activities related to the applied physics group of Dr. Sixl and the ceramics group of Dr. Haldinger. The ceramics group, comprising about 60 people including 18 scientists, was added to corporate research when the Technical Ceramics Division of Rosenthal was purchased by Hoechst.

High T_c research and development involves a total of about 10 people and the emphasis is on components such as tapes, fibers, thick film coatings, thin films, and spray coatings. Collaboration with universities includes those at Keil and Stuttgart.

Hoechst's work with the new BiCaSrCuO material has provided material in which the resistance roll-off begins at more than 100 K but goes to zero at about 80 K. The material was multiphase. Starting with off-stoichiometry material produced a better final product than starting with the presumed stoichiometry. The groups were mapping out the phase diagram at the time of our visit. While the resistive drop was seen and an ac susceptibility change was measured, the dc susceptibility was little changed and a positive value observed. These results are not presently understood.

Hoechst's work has included the YBaCuO compounds, but they have not worked in the LaSrCuO materials. They have used a plasma process to coat tapes of 200-μm thickness on a ZrO_2-Y coating of 200-μm thickness on a 2-mm-thick steel tape. A $T_c(0)$ of about 77 K was observed, but the critical current was very low – $J_c < 100$ A/cm^2 (measured with a 1 mA current). The group's collaborative work with the Karlsruhe group has produced a silver clad wire. Hoechst has the capability of producing very fine powder sizes in the starting materials but saw no advantage to start with powder sizes of less than 1μm. Some disadvantages with respect to superconducting properties were observed for very small powder size.

We were given a tour of the extensive laboratory by Dr. Gauss, a new employee. An automated resistance measuring device and electronics system, a Quantum Design automated susceptometer, SIMS, ESCA, and other equipment of high quality was available and in use – now predominantly on the BiCaSrCuO materials.

Clearly, the Hoechst company has made a substantial and long-range commitment to the development of high T_c superconductors. They have moved quickly (or perhaps have been working for some time) on the BiCaSrCuO material and are maintaining an active program on the YBaCuO materials with the expectations of being involved as suppliers to any developing fabrication industry.

Siemens AG, Erlangen

With more than 25 years' experience in superconducting technology, the Corporate Research and Development Laboratory of Siemens at Erlangen is the largest industrial superconductivity effort in West Germany. It is under the direction of Dr. Rolf Gremmelmaier. Of the total of 39,000 people doing research for Siemens about 3,000 (about equally divided between fundamental research, manufacturing technology and information technology) are located at Erlangen. Siemens spends 11 percent of total sales (up from 8.8 percent 2 years ago) in research and development with 80 percent of that located in its business divisions. For example, the research and development effort for the superconducting magnetic resonance imaging (MRI) magnets is supported mostly by the Medical Division. With the help of the research lab at Erlangen, they have built a 1.25-meter-

bore 4-tesla magnet to study the use of high magnetic fields, high gradients, and high frequencies in medical diagnostics.

In fundamental research there are two divisions working on superconductivity – the Superconductivity and Low Temperature Division under Dr. G. Bogner and the Metallic Research Division under Dr. H.E. Hoenig, total of about 100 people. The first group studies everything from refrigerators to practical superconductors to high field magnets to electrical generators. They are heavily involved in a superconducting generator program funded by, among others, BMFT and Siemens. The objectives are a 110-MVA prototype by 1989 and an 850-MVA machine for study by 1995. For the Metallics Research Division, there has been extensive conductor development, especially in cooperation with Vacuumschmelze GmbH (VAC), a wholly owned Siemens subsidiary and Europe's largest producer of superconducting wire. This work has included laser annealing for Nb_3Al, continuous vapor deposition of Nb_3Ge, and extensive research and development with VAC in Nb_3Sn. They have also developed some superconducting electronics, mostly SQUID integrated circuits for medical applications. Within these two groups and VAC is an extensive accumulated experience – from fundamentals to product sales – in superconductivity.

The studies on the new high T_c superconductors under the direction of Dr. Hoenig involve 20-30 people within these groups and also some at a ceramics division of Siemens in Munich. The support is totally from Siemens, and the work is carried out by redirected staff with no new hires. Three methods were being used to make thin films, ac and dc magnetron sputtering and laser evaporation. At present the dc magnetron method has given the best reproducible results – i.e., most metallic in the normal state, J_c-10^5 A/cm^2 on $SrTiO_3$ substrates, and the most reproducibility on ZrO_2 substrates. Metallography, x ray, and high resolution TEM were used to study the microstructures for correlation and improvement of the J_c's. For example, high dislocation densities, 10^8/cm^2, can be found adjacent to a rough $SrTiO_3$ surface. The study group has produced 1-mm wires with Ag cladding that are 98 percent dense in order to gain experience for conductor development. A hypersonic jet evaporation process (Jet Kote) has yielded superconducting thick films with the advantage of cool substrates. They have also produced the latest BiCaSrCuO materials.

The economic impact of a T_c above liquid nitrogen has been assessed by Dr. Bogner. Indications are that there is little to gain in converters or levitation systems; generators will save about 10 percent in both capital and operating costs but, more importantly, the break-even point is reduced to about 400 MW, which dramatically increases the market; MRI magnets will have about a 15-percent savings, which is only 5 percent of the total system, but in addition, could now be operated in sites remote from liquid helium; and in an interesting case, rf cavities have lower losses up to 9 MHz and at 77 K are about 10 times better than copper.

Overall, Siemens' long experience and wide expertise has kept them strongly involved in the new conductor development.

Walther Meissner Institute for Low Temperature Research, Garching

The Walther Meissner Institute for Low-Temperature Research at Garching is supported by the Bavarian Academy of Sciences and is headed by Dr. Andres. This relatively small research institute has quickly focused on those aspects of superconductivity for which they are known, the thermodynamic properties at low temperatures. Most of their work has been with sintered YBaCuO but they have also done some good optical studies on crystals. In these latter studies they have concluded from Raman spectra that a range of energy gaps may exist. Some excellent specific heat data below 10 K showed large changes with the onset of superconductivity which could be fit with a linear term, but there was no linear term in the thermal conductivity. Magnetization and critical current measurements complete a rather thorough range of studies applied to the new materials and provide one rather striking result: the transition width at T_c is wider in single crystals than in the sintered bulk.

With rather limited resources compensated by expertise, the Meissner Institute is contributing to the overall capabilities and understanding in the study of the new materials.

Max Planck Institute for Solid -State Research Stuttgart

Professor Manuel Cardona is one of the directors of the Max Planck Institute for Solid-State Research (MPI) and has vigorously pursued the application of optical techniques, especially Raman scattering and far infrared spectroscopy, to the high T_c research. Professor Ludwig Genzel and Drs. H. Mattausch and E. Schonherr described the work of the group of about 10 people active in high T_c research. The total MPI staff is about 200 with an additional 100 guests and about 150 students at the Diploma and Ph.D. levels. Professor H. Frohlich is a member of the directors. The search for new materials, their characterization, and properties measurements of solid-state materials are part of the charter of this group.

An active chemistry group of Drs. Mattausch and Schonherr provided the single domain YBaCuO crystals that have permitted Professor Cardona to determine the a, b axis differences in Raman spectra and the subsequent description of the vibrational structure of this material. Some 800 samples of high T_c materials were prepared. Oxygen deficiency in the YBaCuO material has been studied, a rate law dependence found for oxygen removal, and an activation energy determined to be 128 kJ/mole. Accurate weighing of deposited and oxygen-annealed

material provided precision determinations of CO_2 removal when the barium carbonate material is used in synthesis. Raman spectra of comparison samples with MBaCuO (M = Y, Ho, Gd, Sm, Eu) showed the amplitude of a peak at 343 cm^{-1} to have an anomalous temperature dependence in O_7 material: it softened when the sample was cooled below T_c. The assignment of these modes by fitting the theoretical calculations suggests the superconductivity mechanism is connected with the CuO planes in these materials. Infrared reflectivity measurements have been interpreted to obtain a gap at 220 cm^{-1} although complete reflectivity below the gap is not measured. The gap is inferred from the change – depressions in the spectra to peaks in the reflectivity – of IR active modes. Significant work with substitutions has been carried out, Fe replacing Cu up to 5 percent and Co to 10 percent, while maintaining superconductivity. Fluorine substitution produced no higher transition temperature; sulfur substitution for oxygen has been tried. Much of this work has now shifted to the new material, BiCaSrCuO.

Significant work was in progress on the new BiCaSrCuO material. From the earlier (January 22, 1988) Japanese report samples were promptly made with transition temperatures of 85 K for zero resistivity. The largest resistivity drop at the higher temperature, 110 K, is found for 880°C annealing in flowing air. Single crystals were obtained from Hoechst, who had been active in the study of this material in November, 1987; the work at Siemens had apparently started even earlier, with a patent filing on or about 6 April 1987. The Raman spectra have been taken and, at low temperature, some indication of a gap was found on one sample but was not reproduced at the time of our visit. The structure has been under study, probably a distorted orthorhombic, and good knowledge of the AT&T Bell Labs' work and other US and foreign work was apparent. Professor Cardona was preparing to leave for an extended collaboration in the US.

In summary, this effort with mode determinations from single domain YBaCuO crystals is clearly seminal and involves effective interaction between chemists and physicists along with very close ties to industries in Germany and elsewhere, especially the US.

KFA (Kernforschungsanlage) Jülich

The KFA laboratory has 10 permanent institutes and two other experimental groups of finite lifetime that pursue new areas of research. Total personnel is about 250 plus about 70 students including Ph.D., Diploma, and engineering candidates. Some 80 guests have been at the laboratory during the past year. Each of the ten institutes has a director who has a concurrent professorship at a nearby university.

The high temperature superconductivity research is mostly in the Institute for Solid-State Research headed by Dr. H. Wenzl and involves phase diagram studies of single crystal growth, structure studies, nuclear magnetic resonance, photoabsorption, and photoemission measurements. A CRAY-XMP is available to support calculations. Topics of interest include electronic properties, ab initio studies of surface problems, defects, statistical mechanics of polymers, disordered systems, melting, crystallization, and nonlinear dynamics. Exchanges occur with the Institute Laue-Langevin in Grenoble and with US National Labs; Oak Ridge and Brookhaven were noted. KFA's plans include, with the addition of a new group and several electron microscope units, an upgrade of electron microscopy to include atomic resolution.

Dr. Fischer reported that by measurements with sputtered films at various oxygenation levels as determined with volumetric methods, the 90 K and 60 K plateaus in YBaCuO as found elsewhere have been confirmed. Other substrates were used – $SrTiO_3$, ZrO_2-Y, and MgO – and a transition temperature width of 5 K was obtained on MgO with oxygen post anneal. Studies of buffer layers on other substrates of technological interest are planned. A lower temperature of 670°C in a pure oxygen atmosphere has been possible on a silicon substrate. Films with $T_c(0) = 77$ K have been made without a post anneal. Single crystals have been prepared, and substitution with Gd for the rare earth gave an optically untwinned sample.

Rutherford backscattering has been used to study film composition, and theoretical fits to the spectra have been modeled. Scanning tunneling microscope measurements are planned at low temperatures. The KFA people have done vacuum tunneling at dilution refrigerator temperatures. They have interpreted the current-voltage characteristics to give a gap of $2\Delta/k_BT_c = 4.5$. Ion implantation is done with a 7.5-MeV accelerator. Film growth has been studied with channeling and the angular variation measured. The NMR, NQR studies have been carried out on the LaSrCuO and YBaCuO materials. In the YBaCuO material the lack of a signal from Cu suggests a magnetic moment resides on the ion. A discussion of the controversy of the NQR spectra interpretation was given; KFA believes that the 32-MHz signal is related to the Cu2 site. For the Gd-substituted material in the semiconductor oxygenation state, only the Cu1 site is observed. The XPS and EELS techniques are also being used to prove the electronic structure. A brief mention of work with BiCaSrCuO material was given. They obtain resistance drops at 105 K and 83 K and obtain $T_c(0) = 73$ K. Expanded effort is in progress.

The work at Jülich involved people from across the 10 institutes primarily oriented to electronic properties and subsequent applications as electronic components. They are planning to strengthen the superconductivity effort by drawing in a well-known scientist in superconducting devices and combining the superconductor and semiconducting work in one group focused on thin film applications.

KfK (Kernforschungszentrum Karlsruhe)

KfK has probably the largest superconductivity research and development program in all of Europe that is located in one laboratory. Dr. Wolfgang Klose directs the programs there, which are principally conducted in two institutes: the Institut für Technische Physik (ITP), headed by Dr. Peter Komarek, and the Institut für Nuclear Festkorperphysik (INFP), under Dr. Maier. KfK has a long history of major developments and fundamental studies ranging from the most fundamental tunneling studies to the very successful large fusion coil most recently tested at Oak Ridge National Laboratory. This tradition of continued conduct of broad-based superconductivity research and development – and continued success – in one laboratory was, in fact, one of the elements in the decision by the West German ministries to *not* create a new superconductivity research center. While KfK has quickly developed comprehensive programs in the new oxide superconductors it has also continued both fundamental and practical developments in conventional superconductivity. At least two of these developments described below – the NbN multifilamentary and the Chevrel phase conductors – are of major importance and, although they are presently overshadowed by the high Tc materials, will likely have significant impact.

The research efforts in the new high T_c superconductors for 1988 involve 35 man years (more than twice that of 1987) and DM10.7 million for salaries and about DM23 million for equipment and consumables. These resources are spread about equally between fundamental research, synthesis and characterization of special superconductors, technology of applications, and a slightly lesser amount to the development of high fields. The laboratory's work in conventional superconductors, both in the development of thin films and practical wires, but especially in the work with the brittle A15 and other higher T_c superconductors, has provided an excellent basis for a quick and intelligent response with the new oxide materials.

Two developments in conventional superconductivity are worthy of special note. During this previous year the NbN coating process has met with important success in the work of Dr. M. Dietrich. Carbon fibers (of a composition to match the thermal expansivity of NbN) have been bundled into 3000- to 9000-strand bands and passed through a sputtering machine especially designed to allow a 0.5-μm coating of NbN to be applied in a continuous and reasonably uniform fashion on lengths up to 10-meters. Cu coating is separately applied, and the band is coated with indium solder and, finally, plastic. The band has been wound on a 10-cm diameter coil form, and short and long sample tests have been performed. The microstructure shows grains growing normal to the fiber substrate of about 100 Å diameter. Critical currents of about 2×10^3 A/cm^2 are measured on the NbN coating. A reduction by a factor of three occurs in an applied field of 13 T. This development now permits high-field, high-temperature, strain-insensitive superconductors to be made continuously into a practical multifilamentary wire.

The work by Professor R. Flukiger has advanced the prospects for a wire of Chevrel phase material. He has cast a block of this material, using a hot isostatic pressing (HIP) procedure, to obtain full x-ray density material with no loss of sulfur. This $PbMoS_8$ block can be deformed to a wire clad in steel and given a treatment to restore superconductivity. The critical current is reversible, with strain up to 0.8 percent, and a 20-percent reduction of J_c for a few tenths percent strain. A new apparatus was being constructed to use an existing split coil 13-T magnet for measurements up to 19 kA, 10 tons, and 50Hz cycle that will support testing of a 2cm^2 cross section material.

The BiCaSrCuO material was made within 10 days after the Japanese announcement. The synthesis needs extra copper to give the larger resistance drop at 105 K. Susceptibility measurements showed significant drops below T_c. A second step to zero resistance near 80 K was observed accompanied by a further drop in susceptibility. The susceptibility measurements at low frequency showed no dependence on amplitude or current, but for higher (> 10 kHz) frequencies some strange effects have been measured. There is the possibility that free copper could give such a response. Sputtered films show a rollover at 80 K and zero resistance at 45 K. The excellent high-pressure x-ray diffraction equipment is being used to determine the structure of this material under pressures to 250 kbar. A very open diamond anvil with one diamond supported only at the collar and a wide slit is used to permit angular resolution of a narrow line source. The equipment, including temperature control to low temperatures, is well automated except for pressure changes. A positive pressure dependence on T_c has been found up to 20 kbar. The composition has been determined at the Nuclear Solid-State Physics Institute to be $Bi_2Ca_1Sr_2Cu_2O_8$, and sputtered films of 1113 target materials have an 85 K onset, 45 K zero while 2122 material has a 90 K onset.

The KfK people have studied YBaCuO material with these techniques, prepared textured specimens by vibrating the platelet-shaped microcrystals into alignment and fixing in epoxy. The critical current in an applied field showed a rapid decrease at low fields – lower for B parallel to the a, b plane – and then an increase to near 7 T where there is a dropoff. Analysis by the Karlsruhe group extracted an intergrain value of $J_c \sim 10$ A/cm^2. Correlation between increased twinning and critical current was observed with a Gd substituted material that has a normal resistivity of 150 μohm/cm. The method of fiber coating by sputtering is well developed to adapt to these materials, a SiC fiber would withstand the higher sputtering temperatures; a Pd-doped silver wire cladding can be used to permit the higher processing temperature of 950°C. The wire production with the classical supercon-

ductors Nb_3Sn, Nb_3Al and Chevrel phase materials is also ready for adaptation.

In the Institute for Nuclear Solid-State Physics, which collaborates very strongly with the Institute of Technical Physics, a significant effort on sputtered films – magnetron rf and coevaporation of base metals with three electron beam guns – was in progress during our visit. Various substrates – yttrium stabilized zirconia, MgO, sapphire, and others – were being used to produce good films for tunneling and improved critical currents on commercially important substrates. The institute developed a "two stage" process, compared to Stanford University's "three stage" process, in order to achieve directly the tetragonal (rather than amorphous) phase after sputtering. An oxygen anneal then gives the superconducting orthorhombic phase. Various designs of the sputtering targets have been developed including a cylindrical target similar to a commercial Sloan design that uses a high partial pressure of oxygen (2×10^{-1} Torr) and low voltage. Values of J_c to 10^3 A/cm^2 have been achieved on $YZrO_2$ (with very low dispersion of the c axis from the surface normal, $\sim 0.2°$) to much lower values on Al_2O_3 (where dispersion of c axis orientation is larger, $\sim 8°$). The temperature variation of J_c was measured. Comments were made on tunneling results to date – some 50 trials without clear tunneling. The use of indium point contacts permits indium tunneling to be seen at lower temperatures to check the quality of the contact. Ion implantation and Rutherford backscatter are available at the 2-, and 3-MeV van de Graaf accelerators.

A discussion of phonon split band theory was given to indicate better agreement with EELS, XPS, and BIS measurements in LaSrCuO and in substituted MBaCuO material (M = Y, Gd, Pr) where the Pr material does not exhibit superconductivity. A peak at 80 MeV was found to be very sensitive to oxygenation in the LaSrCuO material. Their results suggest a conflict with a local density functional approximation (LDFA) – a strong d-d electron coupling is compatible with an O_2 p band. Strong electron phonon coupling works all right for LaSrCuO but is a problem with the YBaCuO.

In summary, the very strong superconductivity research at KfK stems from an early long-term commitment to conventional superconductivity. The advances in NbN magnet cables and processing of high-density $PbMoS_8$ Chevrel phase material in wires are recent important advances. KfK is well positioned to respond quickly and effectively in the high temperature superconductors as is evidenced by their careful work on LaSrCuO and YBaCuO material. The expectation of future long-term commitment encourages this research as do the extensive collaborations and flux of visitors.